

Summary

INTRODUCTION

California's San Francisco Bay Delta Estuary encompasses the deltas of the Sacramento and San Joaquin Rivers as well as the eastern margins of San Francisco Bay. Extensively modified over the last century and a half, it remains biologically diverse and functions as a central element in California's water supply system. Uncertainties about the future, actions taken under the federal Endangered Species Act (ESA) and companion California statutes, and lawsuits have led to conflict concerning the timing and amount of water that can be diverted from the Delta for agriculture and municipal and industrial purposes and concerning how much water—and of what quality—is needed to protect the Delta ecosystem and its component species.

The Delta is among the most modified deltaic systems in the world. Millions of acres of arid and semi-arid farm lands depend on the Delta for supplies of irrigation water, and approximately 25 million Californians depend on transport of water through the Delta for at least some of their municipal water supplies. Population growth anticipated for the first half of the 21st century is likely to create additional water demands in spite of significant reductions in per capita urban consumptive uses. In addition to supporting these consumptive uses, the Delta provides habitat for animals and plants. The Delta also supports recreational boating and fishing.

Diversions from the Delta are dominated by the exports to the irrigation and urban service areas of the federal Central Valley Project (CVP) and the State Water Project (SWP) service area, which include southern portions of the San Francisco Bay area, the western side of the San Joaquin Valley, and much of southern California. Substantial amounts of water also are diverted upstream for use in the Bay Area and Central Valley cities and farms, and within the Delta itself for local irrigation. Irrigation return flows are discharged upstream and into the Delta itself. Water supplies are highly variable from one year to another.

Despite statewide water conservation efforts, which are particularly pronounced in the urban sector, increasing seasonal restrictions on diversions have been applied, although the total amount of water diverted for export by SWP and CVP has not decreased. The CVP withdraws water from the Delta and conveys it southward into the San Joaquin Valley through a system of canals built and operated by the federal Bureau of Reclamation and various water user groups. Most of this water is used for agricultural purposes; a small amount is contracted for domestic use. The SWP withdraws water separately from the Delta and conveys it southward to agricultural users on the west side and at the very southern end of the San Joaquin Valley and subsequently over the Tehachapi Mountains into the conurbation of the South Coast Basin. Total available supplies to both CVP and SWP have been constrained in recent years by court decisions restricting diversions because of environmental concerns. In addition, many of the levees have become weak and some of the natural riparian zones of the Delta have been eroded.

Resolution of these problems is complicated by water scarcity generally and because alternative solutions impose differing degrees of scarcity for the uses advocated by different groups of stakeholders. The risk of change in water supplies, which could be manifested either by increases in the already substantial intra-seasonal and intra-annual variability or through an absolute reduction in available supplies, underscores the existence of water scarcity and illustrates ways in which such scarcity could be intensified.

In addition to serving economic purposes, Delta water has been managed for other purposes. Since the beginning of CVP operations, water diversions to users outside the Delta have been managed to reduce the effects of salinity intrusion on local water users in the western margins of the Delta. Additionally, the constitution of California requires that the waters of the state be put to "beneficial use." Although not defined, this criterion is subject to judicial review and determination. The enactment of both state and federal environmental laws has led to increased allocation of natural and stored water to environmental (instream) uses. The importance of environmental uses of water has been reflected further in many state regulatory decisions and, more recently, in judicial interpretations of the federal Endangered Species Act and the California Endangered Species Act that have led to specific water allocations. Five taxa of fish residing in or migrating through the Delta (one steelhead population, two populations of Chinook salmon, delta smelt, and green sturgeon) have been listed as threatened or endangered under the federal Endangered Species Act (ESA) and similarly listed under the California Endangered Species Act. There has not been a comprehensive agreement about how to allocate Delta water to these various purposes.

The Current Study

Given the complex backdrop surrounding the California Delta and the importance of this water source to human and ecosystem needs, Congress and the Departments of the Interior and Commerce asked the National Research Council to review the scientific basis of actions that have been taken and that could be taken for California to achieve simultaneously both an environmentally sustainable Bay-Delta ecosystem and a reliable water supply. To balance the need to inform near-term decisions with the need for an integrated view of water and environmental management challenges over the longer-term, the National Research Council addressed this task over a term of more than two years, resulting in three reports.

First, the committee issued a report, *A Scientific Assessment of Alternatives for Reducing Water Management Effects on Threatened and Endangered Fishes in California's Bay Delta*,¹ focusing on scientific questions, assumptions, and conclusions underlying water-management alternatives in the U.S. Fish and Wildlife Service's (FWS) Biological Opinion on Coordinated Operations of the Central Valley Project and State Water Project (December 15, 2008) and the National Marine Fisheries Service's (NMFS) Biological Opinion on the Long-Term Central Valley Project and State Water Project Operations Criteria and Plan (June 4, 2009). The Executive Summary of this report is in Appendix A.

Second, a separate but related NRC panel issued a short report that reviews the initial public (November 2010) draft of the Bay Delta Conservation Plan (BDCP) in terms of the

¹ Available through The National Academies Press: <http://www.nap.edu/>

adequacy of its use of science and adaptive management—*A Review of the Use of Science and Adaptive Management in California's Draft Bay Delta Conservation Plan*.^{2,3}

This third report addresses the following tasks (the full statement of task is in Appendix C):

- Identify the factors that may be contributing to the decline of federally listed species and, as appropriate, other significant at-risk species in the Delta. To the extent practicable, rank the factors contributing to the decline of salmon, steelhead, delta smelt, and green sturgeon in order of their likely impact on the survival and recovery of the species, for the purpose of informing future conservation actions.
- Identify future water-supply and delivery options that reflect proper consideration of climate change and compatibility with objectives of maintaining a sustainable Bay-Delta ecosystem.
- Identify gaps in available scientific information and uncertainties that constrain an ability to identify the factors described above.
- Advise, based on scientific information and experience elsewhere, what degree of restoration of the Delta system is likely to be attainable, given adequate resources. Identify metrics that can be used by resource managers to measure progress toward restoration goals.

The statement of task focuses primarily on science, and does not ask for policy, political, or legal advice. The report organization does not follow the statement of task because the committee concluded the current organization provides a more logical flow. The factors affecting the listed species are discussed in detail in Chapter 3. Future water-supply and delivery options are discussed in Chapters 2, 4, and 5. Scientific uncertainties are discussed throughout the text in Chapters 3 and 4, and the degree of restoration likely to be attainable is in Chapter 4.

CHALLENGES AND OPPORTUNITIES

The challenges of managing water and achieving ecological rehabilitation in the Delta are numerous, including the reluctance of many participants to confront the reality that water is scarce; the distribution of water management responsibilities among many agencies and organizations; the suite of environmental factors (stressors) that affect the structure and functioning of the Delta ecosystem, including the many biological and physical changes that have occurred in the Delta; and the lack of detailed understanding of future socioeconomic, climate, biological, and other changes and the consequent lack of ability to plan for them. The following sections discuss the individual challenges; opportunities are reflected in the conclusions and recommendations.

² Available through The National Academies Press: <http://www.nap.edu/>

³ The summaries of both the recent NRC reports are provided at the end of this report as appendices.

Scarcity

Scarcity means that there is simply not a sufficient quantity of some resource or commodity to satisfy all wants for it. Scarcity is a pervasive phenomenon and it is persistent. Water scarcity has always been a fact in California (save, perhaps, for unusually wet periods), and therefore the committee cannot evaluate the items in its charge above without addressing scarcity. The magnitude or intensity of scarcity has grown over time and it continues to grow because demands have grown. There are numerous manifestations of scarcity. For example, legal rulings that require larger allocation of water to support fisheries and environmental flows are a manifestation of scarcity. Concerns about the Delta itself and differing positions about how Delta waters should be allocated are also manifestations of scarcity. The failure to acknowledge scarcity as a fact of life and to craft water plans and policies to address scarcity has made the management of Delta waters far more difficult than it needs to be. The issue of scarcity is discussed in detail in Chapter 2.

Conclusions and Recommendations

California's Two "Co-equal Goals"

Contemporary planning for water management in the Bay-Delta is directed at two "co-equal goals": providing a more reliable water supply for California and protecting and rehabilitating the Delta ecosystem. There are benefits of having established these goals, but the planning needed to implement these goals has not yet led to clarity on how the inevitable tradeoffs between the goals when water is short will be managed. Thus, the benefits of treating environment and water supply equally cannot be fully realized until some additional conditions are met. The implementation objectives associated with the goals need to be made specific so that when inevitable conflicts between the co-equal goals arise, guidance on how those conflicts should be resolved will be available.

Water-Planning Principles and Guidelines for Addressing Scarcity

The committee recommends consideration of the following principles and guidelines for addressing scarcity in planning:

- Recognize that not all uses of water are always compatible with each other.
- Provide better definition of competing uses; and acknowledge, specify, and account for trade-offs in planning and decision making. The cost of water to users should reflect its scarcity and allocation should be based on analysis that allows for informed decision-making.
- Modify practices that do not reflect the scarcity value of water. The fact of water scarcity does not mean that the state is "running out of water." Although most surface flows have been fully allocated or over-allocated, the state can use a number of tools that optimize the use of existing supplies. As described below there are several tools currently available

for use within existing legal authority. Other tools may require additional legislative authorization.

- Enforce California's constitutional prohibition against non-beneficial, unreasonable, and wasteful water use.
- Protect values recognized under the public trust doctrine.
- Practice water conservation (including improved efficiency and productivity of use).
- Improve groundwater monitoring and regulation in all sectors.
- Consider using water markets to address scarcity. Long-term transfers of water from willing sellers to the state offer a significant opportunity for better management of California's waters consistent with the state constitutional provision. The state could then improve the availability of water for supplemental supplies and instream uses, particularly south of the Delta.

The Need for Integrated, Coordinated Planning

Water management for the Bay and Delta is distributed among many agencies and organizations, a structure that hinders the development and implementation of an integrated, comprehensive management plan. Recent and current Bay-Delta planning efforts have not yet resulted in a resolution of what is best for the environment or for satisfying anticipated water needs.

Conclusions and Recommendations

Those engaged in policy making and management should refresh the overall approach to management of water in California that has not been addressed significantly since the late 1960s, when a partial effort was made in the Porter-Cologne Water Quality Act of 1969, which established the State Water Resources Control Board and nine Regional Water Quality Control Boards.

The current organizational structure (or absence of structure), which lacks clear, unambiguous assignments of authorities and responsibilities, makes it difficult to develop and implement a balanced, sustainable plan. The Delta Plan and other efforts under way attempt to satisfy independent legislative enactments, but not the fundamental principles of water management reflected in the Porter-Cologne Act or the state Constitution. For instance, the current version of the Delta Plan deals at length with issues related to financing of various activities. There is no discussion of benefit/cost, efficiency, or priorities for action, all of which are essential parts of effective resource planning.

The committee is not constituted to recommend a specific organizational strategy, but does conclude that the current structure, with distributed authorities and responsibilities, has not been effective and is unlikely to be effective in the future. Issues related to planning and water management are discussed in detail in Chapters 2 and 5.

Environmental Stressors

Many environmental factors, including water diversions, affect the structure and functioning of biotic communities in the Delta. Although it would be convenient if one or only a few of these factors could be identified as the source of the “problem,” or even ranked with some certainty, it is not possible to do that.

Interactions among stressors and between stressors and ecosystem processes are common and can be synergistic or antagonistic. Nutrient enrichment, toxic chemicals and temperature, for example, are affected by physical forces in the system such as hydrologic and hydrodynamic factors. This complicates the interpretation and evaluation of positive, negative, neutral overall effects of any single stressor on the ecosystem and its attributes. Furthermore, species differ in their responses to most types of stress. The result is a complex biological, spatial, and temporal mosaic of impacts from this complex combination of influences.

The ecosystem and its components do not necessarily respond as a unit to most environmental factors. For example, Chinook salmon spend several years at sea and then return to pass through the Delta as adults to spawn; their eggs and young spend time in Delta tributaries before passing through the Delta on their way to the ocean to grow. Returning adult Chinook salmon always die after spawning, so they are not susceptible to chronic environmental stressors, because they die before they can be affected by them. By contrast, delta smelt spend their entire (short) lives in the Delta and so they can be chronically exposed to contaminants in the water. Being smaller and weaker swimmers than salmon, they likely are more susceptible to changes in flow than salmon. In addition, the behaviors, food, distribution in the water column, and physiologies of salmon and smelt are different, so even if they are exposed for a time to the same adverse environmental conditions, their responses to them almost certainly are different.

The above discussion compared only two species, but other species are important as well, including those that are not listed as endangered or threatened. Other species are part of the ecological community and yet they, too, differ in behavior, distribution, physiology, and susceptibility to a wide variety of environmental conditions, including contaminants. There is a complex interplay between key water quality, habitat, and sustainability issues and the drivers affecting them. Furthermore, uncertainties and scientific gaps further compound the problem.

Conclusions and Recommendation

For all the above reasons, the committee concludes that only a synthetic, integrated, analytical approach to understanding the effects of suites of environmental factors on the ecosystem and its components is likely to provide important insights that can lead to enhancement of the Delta and its species. Nevertheless, the committee has evaluated several stressors in terms of their general importance. Those evaluations are summarized below and presented in detail in Chapter 3.

Given the diverse set of organisms and processes that constitute the Delta ecosystem, the ultimate success of any approach targeted to particular species seems doubtful. In contrast, broad standards established admittedly in the face of some uncertainties, do provide broad protection for the ecosystem, i.e., they adhere to the precautionary principle of doing no harm, but do so at higher water cost, potentially using water that could be used to support economic activity, sanitation, and other needs. Thus, the hard decisions will need to be made about

balancing different kinds of risk. These will be matters of policy rather than being the result of a straightforward application of “good science.” Exactly because statistical correlations are not adequate to fully explain the responses of aquatic species to either flows or flow pathways, continuing the effort to better understand the processes that control the implications of both flows and flow paths is essential into the future.

Although many stressors are interacting in a complex way, some conclusions are possible with respect to individual stressors.

For migratory salmonids, and probably green sturgeon, dams are significant stressors. They impede passage, cause the loss of spawning and rearing habitat, change the abundance of predators, and affect temperature and flow.

Migrating salmon and steelhead smolts appear to incur substantial levels of mortality during Delta passage. Increasing passage of smolts through Yolo Bypass to reduce Delta passage may be a viable action for Sacramento runs.

Entrainment effects of SWP and CVP pumping are likely large in some years for some species, and thus entrainment acts as an episodic stressor that has a significant adverse effect on delta smelt population dynamics, although it is very difficult to quantify the effects in simple ways.

There is room for improvement in managing volume and timing of flows and flow paths. The committee re-emphasizes the need for life-cycle modeling and a collaborative process to reduce the paralysis that can occur from the adversarial use of models and to encourage cross-comparisons and cross-fertilization. The recent increase in life-cycle modeling for both delta smelt and salmonids is an encouraging development.

The committee has not analyzed the benefits and disadvantages of an isolated conveyance facility, because not enough specific information was available about it, and we make no recommendation with respect to its adoption as a major part of water management in the Delta. However, the committee does recommend that before a decision is made whether to construct such a facility and in what form, the sizing of the facility, its location, and the diversion design and operation, including the role of current diversions, should be analyzed as part of any integrated Delta plan, and compared to alternative water management options, including current operations.

Changes in nutrient loads and concentrations in the Delta and Bay, especially those for nitrogen and phosphorus, are stressors of increasing concern from water quality and food web perspectives. Toxic pollutants such as selenium also appear to be significant stressors, especially for sturgeon, with San Francisco Bay and the San Joaquin River being the areas of greatest concern.

The stressors also interact with each other and with changes in salinity, turbidity, and freshwater discharges resulting from hydrologic changes in the Delta and its tributaries, changes that have been attributed to water exports, changes in land use, and changes in the morphology of the Delta. The latter factor, caused by canalization and the abundance of hardened structures that also have eliminated tidal wetlands, has affected delta smelt by changing their aquatic habitats. Support for better understanding the processes that link flows, habitat structure and habitat characteristics such as salinity, turbidity and temperature should remain a high priority. Reductions in outflow caused by diversions tend to reduce the abundance of some Delta and Bay organisms.

Introduced species have caused dramatic changes in habitat, prey, and predators of the listed fish species in the Delta. Introductions of nonnative species will continue into the future as

management controls that substantially reduce risk are difficult and expensive to implement. Changes in human activities and climate change could exacerbate the frequency of invasions and persistence of invading organisms in the future. Early detection through monitoring is useful in order to prepare for likely changes to the ecosystem.

Largely because negative effects of hatcheries are difficult to observe, the committee cannot reach a conclusion as to whether and how much hatcheries have contributed to the decline in wild populations of salmonids in the Central Valley. The committee judges that adoption of recent conservation guidelines under a unified hatchery management plan will reduce (but not eliminate) risk to wild populations from hatcheries, and probably represents the most viable option for maintaining populations of salmonids in the Central Valley unless or until other methods are found to increase the productivity of wild populations.

Coastal ocean productivity is one of the most significant factors determining the ocean survival of juvenile salmon and the number of adult salmon that return to spawn. When ocean conditions are unfavorable for salmon and steelhead, those effects can be partially ameliorated by increasing the diversity of wild and hatchery salmon ocean entrance timing.

Currently, disease does not appear to be a significant stressor factor for juvenile or adult salmon or other fish species in the Delta.

Consideration of the large number of stressors and their effects and interactions leads to the conclusion that efforts to eliminate any one stressor are unlikely to reverse declines in the listed species. Opportunities exist to mitigate or reverse the effects of many of the above stressors. To make it more likely that any actions to rehabilitate the ecosystem are cost-effective, continued effects analyses, modeling, and monitoring will be needed.

Environmental Change and Ecosystem Rehabilitation

Climate change is one of the most challenging and important issues confronting the management and rehabilitation of the Delta ecosystem. Changes in climate are expected to have profound effects on the physical and ecological structure of the Delta as well as the nature of water issues in the California. The cascading effects of climate change begin with increasing air temperature, which over the 50-year planning horizon of the Delta's BDCP, is predicted to increase between 1° and 3°C. As a result, snowmelt will occur earlier than currently, and more winter precipitation will fall as rain, as opposed to snow, than currently. The changes are expected to have large effects on temporal and spatial hydrologic patterns even if the average annual precipitation volume did not change.

In addition to changes in hydrologic patterns, sea level also is expected to rise as a result of climate warming. Sea-level rise would interact in complex ways with altered hydrologic patterns and the effects are not easy to predict. However, it does seem clear that the combination of sea-level rise and altered hydrologic patterns would increase the risk to Delta infrastructure, such as levees.

Increased temperature likely would reduce the distribution of salmonids in the Central Valley. In many parts of their range they encounter summer temperatures near the lethal limit for them. The frequency and duration of such temperatures is expected to increase, and their effects likely would be exacerbated by changes in hydrologic patterns.

If the climate projections are correct, more frequent extreme events will increase the need for Central Valley water for both environmental and human uses. In this case, managers may be

asked to consider hard choices. While such the predicted changes may not come to pass, the committee encourages continued critical and comprehensive studies of the full range of future possibilities and how to adapt to climate change. The implications of climate change for the Delta and for environmental rehabilitation and water supplies are discussed in detail in Chapter 4.

Conclusions and Recommendations

Habitat loss and alterations, climate change, and unpredictable levee failure pose significant challenges in the formulation of plans for sustaining the Bay and Delta ecosystem. However, there are many opportunities to steer the future evolution of the ecosystem by addressing future challenges.

Extensive physical changes in the Delta ecosystem and the tributary watersheds, and continuously evolving changes, such as land subsidence in the Delta islands, will not allow the re-creation of habitat as it once existed in the pre-disturbance state. Delta restoration programs will need to balance consideration of an ecosystem approach with the ESA's emphasis on individual species. Programs will need to focus on the interaction of biological, structural, and physical aspects of habitats and how they may change in the future. Even without ESA-listed species, there still would be a need to guide the ecosystem toward desirable states.

Assessments suggest that many species will be affected by changes in the pattern and types of precipitation. Changes already are being observed. Projected increases in the mean sea level and the extremes have the potential to increase the frequency of levee failures and inundation of islands, in part because the land inside the levees continues to subside through oxidation of peat. Sea level rise also has the potential to enhance saltwater intrusion and alter water quality.

Planning and evaluation of future environmental and economic scenarios will need to address the uncertainties in projections, integrated analysis, and the development of risk management strategies (e.g., adaptive management). The uncertainties are higher about the environmental aspects of operations than about the reliability aspects of water deliveries. Climate change implications and the continued increase in water demands in the Bay-Delta system and beyond will exacerbate the competition for water and limit the ability to meet the co-equal goals.

Future planning should include the development of a climate-change-based risk model and analysis that incorporates data on the actual changes in Delta conditions as well as alternative future climate scenarios and their probability. The real challenge is deciding how to adapt to a new environment. Strategies to deal with the expected and unprecedented changes will need to consider many factors, including targeted demand management, increased surface and groundwater storage consistent with minimizing environmental impacts, enhanced flexibility in the water management system through operational optimization and maximum flexibility for moving water, and developing an understanding of and establishing environmental flows for the ecosystem.

The instability and interdependence of levees—failure of one levee can affect others—are likely to be major issues for achieving any measure of water-supply reliability or ecosystem rehabilitation. Continuing the status quo of improving levees will not always be the most environmentally sustainable or economically defensible response in the years ahead. Changes in

the levee system, and even removal or modification of some levees, could be good for at least parts of the ecosystem.

Resource managers dealing with the Delta will need to determine the degree of “restoration” achievable through intervention and adaptation. The Delta as it existed before large-scale alteration by humans cannot be recreated. With respect to species, habitats, productivity and other aspects, the future Delta will still be a functioning ecosystem but different from the one that exists today. However, there is a considerable capacity to guide the direction of the Delta towards a more desirable future by focusing on a functioning resilient ecosystem without abandoning individual efforts to protect individual native species. Achieving the above will require extensive, thoughtful, and transparent planning. That planning will need to include finding ways to reconcile diverse interests without pretending that everybody can have what they want.

The Role of Science and Planning: A Path Forward

Science is necessary to inform actions and proposals related to restorations of all kinds. However, science alone does not provide the entire prioritized, integrated analysis that the committee recommends. For instance, science can provide information on options regarding the control of ammonium to maintain an adequate food supply for fish, on the consequences of different schedules for investment in Delta levees to protect agriculture, and on the degree of effectiveness of future diversion restrictions to protect salmon in the mainstream of the Sacramento River. However, science cannot decide which choice is the best policy. That requires societal and political considerations as well and information on potential benefits and costs. Using the best science is only part of what is needed to resolve the competing interests. The role of science, including its limitations, is discussed in detail in Chapter 5.

Conclusions and Recommendations

The committee concludes that the lack of explicitly integrated comprehensive environmental and water planning and management results in decision-making that is inadequate to meet the Delta’s and state’s diverse needs, including environmental and ecological conditions in the Delta. In addition, the lack of integrated, comprehensive planning has hindered the conduct of science and its usefulness in decision making. Lack of transparency exacerbates these matters and erodes public trust.

The committee recommends California undertake a comprehensive review of its water planning and management functioning, and design modifications to existing responsibilities and organizations that will anticipate future needs including those identified in this report. These needs include dealing with scarcity, balanced consideration of all statewide water use practices and water-engineering alternatives; and adaptive management that can adjust to changing conditions. The result should be that regions such as the Delta can be effective partners in a coordinated statewide effort.

The committee makes no recommendation of any specific organizational strategy for institutional changes. Any strategy should incorporate the public’s desires and achieve the public’s trust while allowing for decisions to be made.

Delta conditions identified in previous chapters indicate that scarcity of water for all needs will become severe. While more effective planning is being developed, the state will need to use its water resources efficiently and productively. A variety of tools are available, including demand-side management (conservation, including more-efficient and more-productive water use) and supply-side management (water transfers conducted by the state or within a new central planning function, new sources of supply, more-integrated management of ground- and surfacewater, enforcement of the constitutional reasonable and beneficial use limitations and invocation of the state Public Trust Doctrine to reconsider past allocation decisions). Thus reliability-dependent users (urban, industrial and agricultural) would have some long-term confidence that supplies will be more predictable. As part of its oversight of such transfers, the state needs to insure that necessary instream flow levels are maintained. Continued, substantial investments in monitoring, modeling, and other research to inform policy choices will be essential.